International Journal of Engineering Research
Volume No.5, Issue No.12, pp :936-938

ISSN:2319-6890 (online),2347-5013(print)
1 December 2016

Excitonic Conversions in Semiconductors

Saliou NDIAYE*, Mamadou NIANE, Modou FAYE, and Bassirou BA
Laboratoire des Semi-conducteurs et d'Energie Solaire de la Faculté des Sciences et Techniques de l'Université Cheikh Anta Diop de DAKAR, BP 5005, Dakar-fann, Sénégal
E-mail : ndiayesaliw@yahoo.fr

***Abstract:** Westudied the influence of parametersthatgovern the excitonic conversion phenomena in semiconductors. In thisstudywedefined a surface conversion velocity of excitons to free electron-hole pairs b_s and a parameter of exciton dissociation in the space charge layer b (x) related to the electricfield E(x). The influence of b_s on the electrons and excitons densities and on the short-circuit current shows thatthisparameteris a generationterm for electrons and a recombinationterm for excitons. In the organicsemiconductorwhere the excitons have a very short lifetime and a binding energysuperior to thermal energy, an exciton conversion model is essential to increase the performance of thesesolarcells. Our studyshowedthat the short-circuit current has a high value when the exciton conversion speed is of the order of 10^4 cm.s^{-1}.*

Keywords: Exciton, excitonic conversion, binding coefficient

I. Introduction

Excitons have a very short lifetime τ_{ex}, on the order of nanoseconde [1-4]. In inorganic materials, their diffusion length can reach 4µm and their binding energy is relatively low (14,7meV for silicon), thermal energy is generally sufficient to dissociate the electron and the hole of the exciton. However, in organic materials, excitons have a shorter diffusion length and their binding energy varies between 0.4 and 1.4 eV. It takes the presence of a local electric field to dissociate the two particles [5-7]. If excitons are not converted into free electron-hole pairs meanwhile τ_{ex}, the electron and hole recombine and the energy is transformed into a new photon or heat. The aim of our work is to study the excitons conversion phenomena into free electron-hole pairs in the semiconductor. Our study model is an extension of the basic model of Green where the space charge layer is taken into account. We model by a coefficient $b_s$excitonic conversions to the surface of the base and by a non-uniform coefficient b (x), excitonic conversions in the space charge layer (SCL). We study indeed the influence of b_s on the densities of electrons and excitons generated in the base and on the short-circuit current.

II. Study model

Our study model, developed in the article of M. Burgelman is an extension of the basic model of Green and Zhang [5].
The space charge layer which was not taken into account the subject of serious study. Indeed, we believe that in this area where there is an electric field E(x), all excitons are dissociated into free electrons and holes that participate in the current.

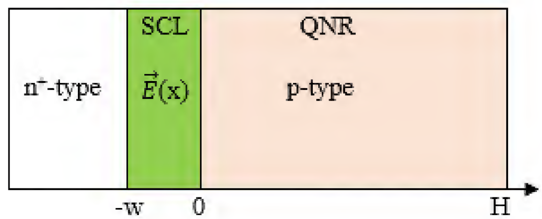

Fig.1. Schemaof the solarcell

Thus, to include drift of electron in the space charge layer, we have added a term « $\mu_e \frac{d}{dx}\left[E(x)\Delta n_e\right]$» in the differential equation of the electron density [5]. However, that excitons remains the same as, in the space charge layer all excitons dissociate into free electrons and holes. This leads to the following two coupled differential equations:

$$D_e d^2 \frac{\Delta n_e}{dx^2} + \mu_e \frac{d}{dx}\left[E(x)\Delta n_e\right] = \frac{\Delta n_e}{\tau_e} + b(\Delta n_e N_A - \Delta n_{ex} n^*) - G_{e0}\exp\left[-\alpha x\right] \quad (1)$$

$$D_{ex} d^2 \frac{\Delta n_{ex}}{dx^2} = \frac{\Delta n_{ex}}{\tau_{ex}} - b(\Delta n_e N_A - \Delta n_{ex} n^*) - G_{ex0}\exp\left[-\alpha x\right] \quad (2)$$

E (x) is defined as follows [5]:

$$E(x) = E_m \frac{|x|}{W}; \quad -W \le x \le 0 \quad (3)$$

$$E(x) = 0 \quad ; \quad 0 \le x \le H \quad (4)$$

To solve analytically this system, we will break down into two systems: A system that takes into account only the quasi-neutral region (QNR) and another that describes the space charge layer (SCL). Thus, we obtain:

In quasi-neutralregion (QNR)

In the QNR electric field E (x) is zero. We then get:

$$D_e d^2 \frac{\Delta n_e}{dx^2} = \frac{\Delta n_e}{\tau_e} + b(\Delta n_e N_A - \Delta n_{ex} n^*) - G_{e0}\exp\left[-\alpha x\right] \quad (5)$$

$$D_{ex} d^2 \frac{\Delta n_{ex}}{dx^2} = \frac{\Delta n_{ex}}{\tau_{ex}} - b(\Delta n_e N_A - \Delta n_{ex} n^*) - G_{ex0}\exp\left[-\alpha x\right] \quad (6)$$

The solving method of this system of differential equations is made in the articles ofCorkish and Zhang[1-2].

Solvingthisequation system involves the followingboundary conditions [11]:

At the junction:

$\Delta n_e(0)=0$ (7)

$\Delta n_{ex}(0)=0$ (8)

At the rear face

$$D_e \frac{d\Delta n_e}{dx}(H) = -S_e \Delta n_e(H) + b_s \Delta n_{ex}(H) \quad (9)$$

$$D_{ex} \frac{d\Delta n_{ex}}{dx}(H) = -S_{ex} \Delta n_{ex}(H) - b_s \Delta n_{ex}(H) \quad (10)$$

S_e and $S_{ex}$are respectively the recombination velocity of electrons and excitons in the rear surface.

b_s is the surface conversion velocity of excitons into free pairs electron-hole [11].

Indeed $S_e \rightarrow \infty$corresponds to an ohmic contact and $S_e = 0$ to a perfect surface .

Equations (7) and (8) respectively reflect the non- accumulation of electrons and perfect dissociation of excitons into free electrons and holes at the junction while the equations (9) and (10) are the phenomena of electrons and excitons recombination and excitonic conversions to the back surface.

✓ **In the space charge layer (SCL)**

In the space charge layer, we have:

- All excitons dissociate into electron - hole free because of the electric field E(x): $\Delta n_{ex} = 0$

- Coupling phenomenon gives way to the excitonic conversion which is modeled by the coefficient $b(x) = A_0 \exp\left[\frac{E(x)}{E_0}\right]$ (11)

A_0 and E_0 are constants determined by the boundary conditions of the SCL:$b(0) = 10^{-15}$ $cm^3.s^{-1}$ and $b(-W) = b_{max.}$

b_{max} with varying between 10^{-15} $cm^3.s^{-1}$ and $10^{-7}cm^3.s^{-1}$.

- The electron recombination rate is derived from the formula of Shockley - Read, thus written [8]:

$$U_{eh} = \frac{\Delta n_e \Delta p - n_i^2}{\tau_e(2n_i + \Delta n_e + \Delta p)} \quad (12)$$

In the depopulated area such as a space charge zone, the product $\Delta ne \times \Delta p$ is negligible before n_i^2 as Δn_e and Δp relative to n_i [8].

The recombination rate is then: $U_{eh} = -\frac{n_i}{2\tau_e}$ (13)

Equation (II.10) becomes:

$$D_e \frac{d^2 \Delta n_e}{dx^2} + \mu_e \frac{d}{dx}\left[E(x)\Delta n_e\right] = -\frac{n_i}{2\tau_e} + b(x) N_A \Delta n_e - G_{e0} \exp\left[-\alpha x\right] \quad (14)$$

n_i is the intrinsic concentration

Solvingthisequation uses the followingboundaryconditions:

$\Delta n_e(-W) = N_D$ (15)

$\Delta n_e(0) = 0$ (16)

N_D is the concentration of donor atoms

III. Results and discussion

We apply our results to organic semiconductors whereas a binding coefficient of excitonsb = 10^{-15} $cm^3.s^{-1}$, recombination velocity $S_{ex} = 10^2$ $cm.s^{-1}$ and $S_e = 10^2$ $cm.s^{-1}$ and a doping level $N_A = 10^{17}$ cm^{-3}.

III.1. Influence of surface conversion velocity of excitons on the carriers density

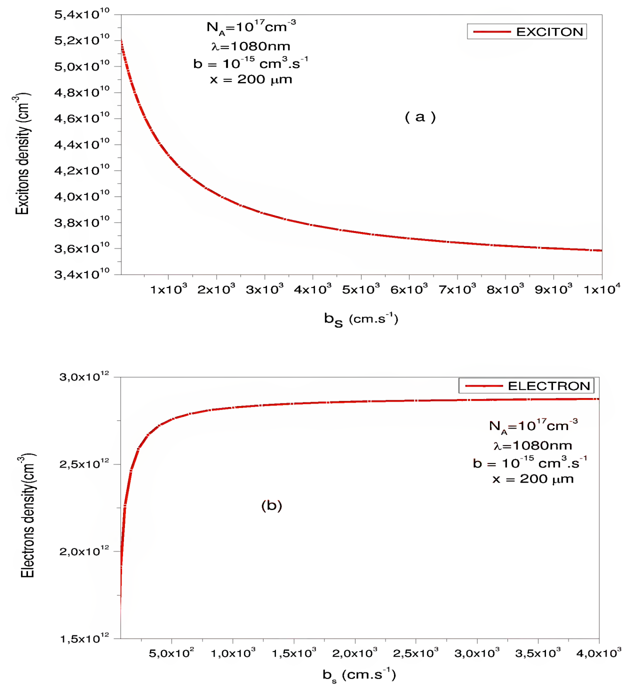

Fig. 2.Densities of excitons (a) and electrons (b) as a function of the exciton surface conversion velocity b_s.

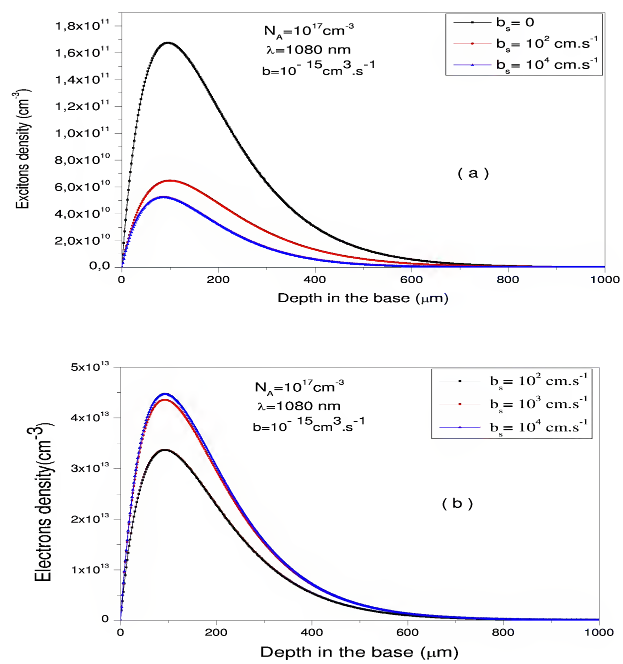

Fig. 3. Exciton density (a) and electrons density (b) as a function of depth in the base for the following values of b_s: 10^2 $cm.s^{-1}$, 10^3 $cm.s^{-1}$ and10^4 $cm.s^{-1}$. $S_e= S_{ex} = 10^2$ $cm.s^{-1}$

Figure 2 and 3 show that the electron density increases as exciton surface conversion velocity b_s.whereas excitons decreases with. The curves have higher slopes for low values of

doi : 10.17950/ijer/v5s12/1213

b_s. Indeed, the conversion of the excitons increases the number of electrons present, thus enhancing the density of free electrons. However, a strong conversion of the excitons increases recombination events and screening which explains the low slope of the curve in the high values of b_s.

III.2. Influence of surface conversion velocity of exciton on the short-circuit currents

We maintain the values of predefined parameters. By considering three values of exciton surface conversion velocity $b_s = 10^2$ cm.s^{-1}, $b_s = 10^3$ cm.s^{-1} and $b_s = 10^4$ cm.s^{-1}, it was possible to plot Figure 4 which reflects variation in short-circuit current as a function of the wavelength for each value of b_s. We find that the variation of exciton surface conversion velocity does not change the wavelength corresponding to the maximum photocurrent generated by each of the charge carriers. However, there is a lowering of the photocurrent generated by the excitons and increasing that generated by electrons. Exciton surface conversion velocity is a generation term for electrons and a recombination term for excitons.

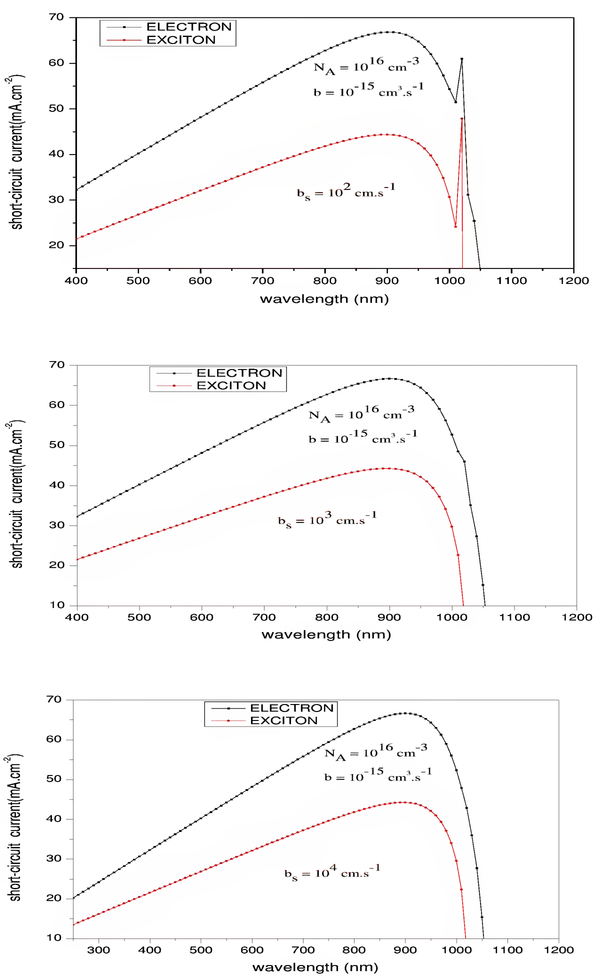

Fig.4. Short-circuit currents generated by electrons and excitons as a function of wavelength for $b_s = 10^2$cm.s^{-1}, $b_s = 10^3$ cm.s^{-1} and $b_s = 10^4$ cm.s^{-1}

IV. Conclusion

We studied in this article excitonic conversion phenomena in semiconductors. This paper is a continuation of the work of Burgelman. This study applied to organic semiconductor that shows the performance of these materials in the production of photovoltaic currents require excitonic conversion velocity greater than the exciton recombination velocity. This is possible when the local electric field is very high. Using backfield solar cell based on organic semiconductor promote a strong excitonic conversion, which would decrease the excitonic recombination.

References

i. R. Corkish, D. S.P.Chan ,M. A. Green , Excitons in silicon diodes and solarcells: A three-particletheory, Journal of AppliedPhysics, vol. 79n.1, January 1998, pp. 195-203.

ii. Y. Zhang, A. Mascarenhas , S. Deb , Effects of excitons on solarcells, Journal of AppliedPhysics, vol. 84n.7,octobre 1998, pp. 3966-3971.

iii. O.A. Niasse, B. Mbengue, B. BA, A. Ndiaye, I. Youm, Effects of excitons in the quantum efficiency of the solarcellCdS / CdTe by the model of the dielectricfunction, Review of RenewableEnergy vol. 12 n. 3,September 2009, pp. 501 – 512.

iv. D. E. Kane, R. M. Swanson, Effect of exciton on visible stripshrinking and transport of semiconductor,Journal of AppliedPhysics, vol.73 n.3, February 1993, pp.1193 – 1197.

v. M. Burgelman, B. Minnaert, Including excitons in semiconductorsolarcellmodeling, Thin Solid Films, vol.511 n.512, Junuary 2006, pp.214-218.

vi. J.Barrau, M.Heckmann,M. Brousseau, Experimentaldetermination of exciton formation coefficient in silicon, Journal ofAppliedPhysics. Chem. Solids, vol.34n.11, November1973, pp.1757-2028.

vii. S. Zh. Karazhanov, Y. Zhang, A. Mascarenhas, S. Deb, The effect of excitons on CdTesolarcells, Journal of AppliedPhysics, vol.87n.17, June 2000, pp.8786-8792.

viii. H. Mathieu and H. Fanet, physics of semiconductors and electronic components, 6th edition, Dunod, Paris, (2009).

ix. R. D. Schaller, V. I. Klimov, Multiexcitongeneration in quantum dots, Physical ReviewLetters, vol.92 n.18, May 2004.

x. Ching-Fuh Lin, Miin-JangChen,Eih-Zhe Liang, W. T. Liu, C. W. Liu, Reducedtemperaturedependence of luminescence fromsilicon due to field-induced carrier confinement, AppliedPhysics Letters,vol.78 n.3,January2001, pp. 261-263.

xi. R. Fisher, J. Feldmann, E. O. Gobel, Hot-Exciton Relaxation

$Cd_x Zn_{1-x}Te$/ ZnTe Multiple Quantum Wells, Physical Review Letters, vol.67 n.1, July 1991, pp.128-131.

doi : 10.17950/ijer/v5s12/1213